

RADARSAT Program

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ABSTRACT

With the launch in 1995 of RADARSAT I, its first Earth observation spacecraft, Canada will start supplying timely Synthetic Aperture Radar (SAR) data to users around the world. The RADARSAT SAR will operate at C-band and HH polarizations in a polar orbit, crossing the equator at dawn-dusk. It will offer to users options in the selection of swath size, resolution size, and incidence angle range of observation to suit a particular location and revisit and geophysical information needs. Works on the implementation of RADARSAT system (spacecraft and ground segment), operation planning, and application and user developments are progressing well. The chosen distributor is making preparations to market RADARSAT data internationally. An announcement for applications demonstration and research opportunity is to be issued soon to the international user community. RADARSAT II, as the follow-on to RADARSAT I has been approved to ensure continuity of SAR data under the RADARSAT program for at least a ten year period.

INTRODUCTION

The RADARSAT program of the Canadian Space Agency (CSA) is a central and major element of the Canadian Space Program. The RADARSAT program was initiated in 1980 and was given go ahead for implementation in 1989 after the completion of definition and preliminary development works in Phases A and B (Parashar et al, 1993). The program, then approved, included construction, launch and operation of Canada's first Earth observation spacecraft - RADARSAT I, and establishment and operation of associated ground facilities. RADARSAT I will carry one instrument or sensor, a versatile Synthetic Aperture Radar (SAR) operating at C-Band (5.3 GHz) with Horizontal transmit and Horizontal receive (HH) polarizations. The acquisition with the subsequent ground reception, processing and distribution of SAR data will be programmed to meet user requests. Users around the world as a result will receive operational access to global SAR observations over the scheduled 5 year spacecraft life after its launch in 1995.

One of the purposes of the RADARSAT program is to contribute to the creation of a viable international market for remote sensing data, information products and services (McNally and Parashar, 1993). This is to be accomplished by providing SAR data commercially to the worldwide remote sensing user community for operational as well as other purposes. Development of an international market, especially for operational applications, will require a continuing supply of SAR data. This need for SAR data continuity has been recognized and CSA is planning for follow-on missions to

RADARSAT I through the Canadian Long Term Space Plan (LTSP). The LTSP has been recently approved by the Canadian Government.

RADARSAT I MISSION

A detailed overview of all aspects of the RADARSAT I mission (mission requirements, spacecraft bus and payload, ground control and data processor, applications, etc.) is contained in a special issue on RADARSAT of the Canadian Journal of Remote Sensing (CJRS, 1993). The RADARSAT I mission has been developed by Canada in collaboration with the United States of America (USA). The spacecraft will be launched by the National Aeronautics and Space Administration (NASA) of USA using a Delta II rocket from the Western Test Range. In return for this contribution of the launch and related services, the USA Government (NASA, National Oceanographic and Atmospheric Administration (NOAA), and other Executive branches) will receive for its internal use a pro-rata share of the SAR on-time available during the RADARSAT I mission. CSA will also be splitting the available SAR on-time with the private sector, i.e. a Canadian company, RADARSAT International Inc. (RSI) which has been assigned the worldwide distribution rights for the RADARSAT I SAR data. These rights are in return for financial contribution to the program such as for the ground SAR processing facility in Canada. RSI will undertake the commercial data sales worldwide and pay revenues to the Canadian government to offset cost of the RADARSAT I mission. This has resulted in a data policy prohibiting the distribution of data to third parties, which means that the users within the Canadian and the USA governments will receive SAR data for internal government use only. All other users, including value-added resellers, will get their data through RSI.

The RADARSAT mission is to supply and distribute global SAR data to the worldwide user community for such applications as ice mapping, ocean surveillance, agriculture and forestry monitoring, geological resource mapping and environmental studies. The development of applications and end users to utilize these applications and expand the economic benefits is an integral part of the mission. In support of RADARSAT, the Canada Centre for Remote Sensing (CCRS) has been developing SAR applications for many years, using data from its CV-580 aircraft and ERS-1. Moreover, it has recently acquired aircraft SAR data sets in ten countries under GlobeSAR with funding from CSA. The GlobeSAR data will be used to simulate RADARSAT data and train users in these countries, in support of the marketing effort by RSI. Also, CSA, NASA, and RSI are instituting an Applications Development and Research Opportunity (ADRO). Proposals for using RADARSAT data will be selected and sponsored through a competitive process under the ADRO program.

System Elements

Overview: The RADARSAT mission (Figure 1) is conceived as an end-to-end system with the requests from the global user community received by the order-desks and the corresponding SAR data products delivered to users from the processing facilities. The Mission Control System (MCS) in Canada will be the centre of operations for the RADARSAT mission. The MCS will be responsible for controlling the spacecraft and programming it for SAR data acquisition and transmission to ground as well as scheduling the ground elements for data reception, processing and delivery. The SAR data will normally be acquired when the spacecraft is within view of one of the ground data receiving stations. However, two on-board tape recorders are being provided to acquire SAR data for any part of the globe and dump the recorded data when the spacecraft is within the Canadian station mask. The tape recorders will, therefore, allow global operational coverage independent of the location of ground receiving stations. The central planning and execution approach through the MCS is largely in response to the operational application requirements, such as for ice monitoring by the Canadian Ice Centre which requires less than four hours turn-around time (time between SAR observations and delivery of data to users). While the emphasis is in meeting data acquisition, processing, and delivery needs in a timely manner, the system will also be archiving the raw SAR data acquired. The MCS will keep an up-to-date catalogue of archived data and the order-desks will determine in consultation with the customer, if the given data request needs to be met through a retrieval from archives or an acquisition or a combination of the two.

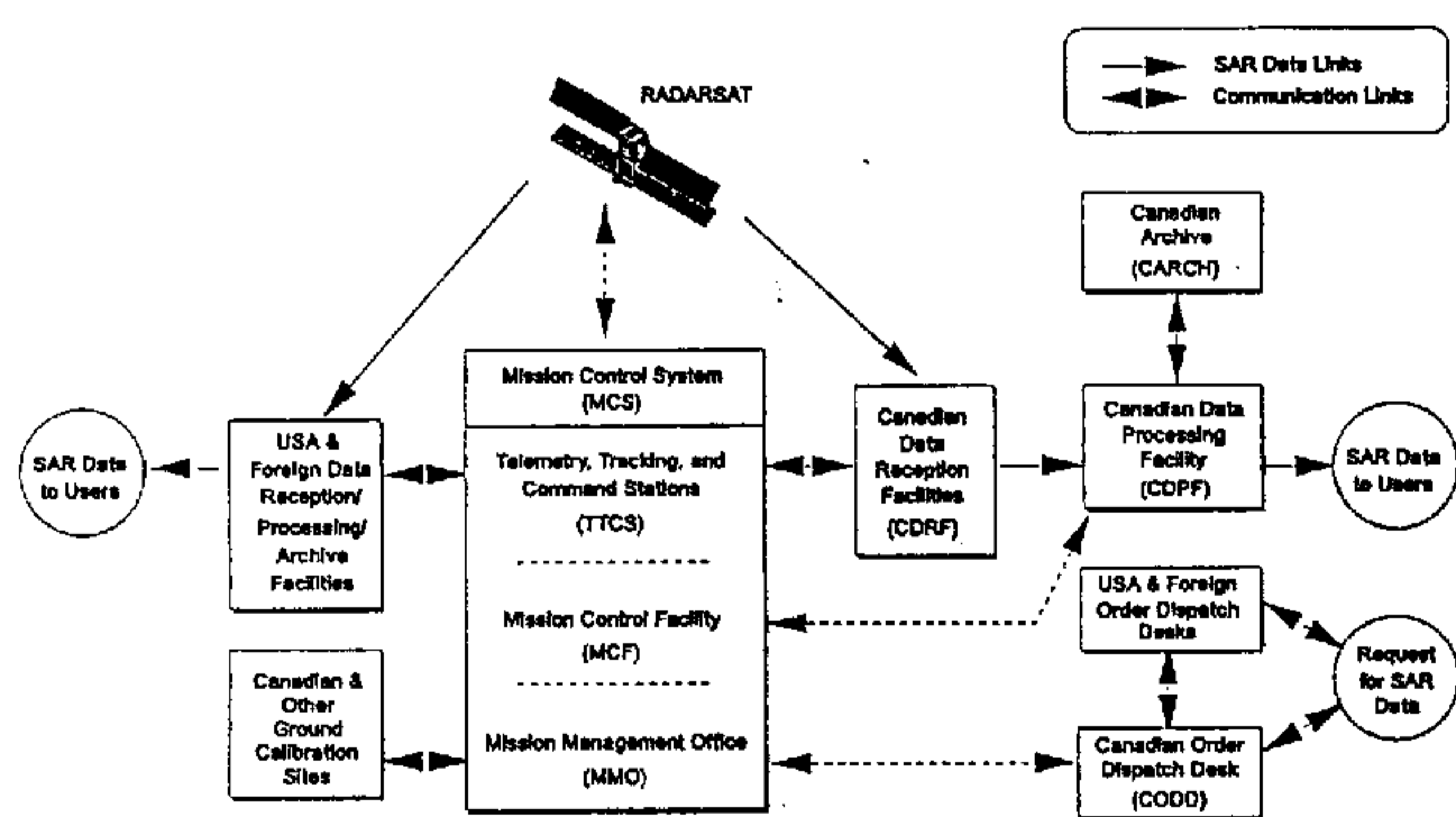


Figure 1.
RADARSAT Mission Concept

Order-Desks: The order-desks will be the primary interface with the users and assist them in preparation of their data request. These desks will be geographically distributed with their work stations linked to the MCS through a wide area network. Five desks are planned for the present to serve the needs of various partners and user groups. These desks are: USA Government, likely to be at the receiving station in Fairbanks, Alaska; Canadian Government at CCRS in Ottawa; Ice Centre in Ottawa; CSA in St. Hubert with the MCS, and RSI in Vancouver. Each of these will collate and prioritize requests from its own user constituency and send these to the MCS. All requests outside of the data allocations of USA and

Canadian governments will be through the RSI desk which will be connected to its client 'feeder terminals', such as at the data receiving stations.

Mission Control System (MCS): The user requests from the order desks will be processed and put into the data acquisition, reception and production schedules by the MCS. These schedules will be developed based on the 24 day repeat cycle, in advance of the acquisition date and the relevant portions will be distributed to the ground reception and processing facilities. For acquisition, each day the MCS will generate files containing the time-tagged commands for that days operations. These files will be unlinked to the spacecraft for executing the operation of the SAR, the tape recorders, and the downlink data transmitter. These files will also contain commands for orbit manoeuvres, and other maintenance activities for the spacecraft including telemetering to ground the status or health of the on-board equipment.

The entire system with all its functions and transactions will be managed by the Mission Management Office (MMO). The MMO will coordinate the operations of three main elements: mission planning, spacecraft control and data handling through an operation plan. This will involve tracking and resolving any conflicts in the use of resources of the spacecraft and ground elements (e.g. SAR on-time and mode selections, tape recorder usage, receiving station availability, processing priorities, and calibration activities). Accordingly, the MMO will ensure that the operational risks are minimized and system performance optimized within the technical constraints while meeting the data needs of users. The Mission Control Facility (MCF) will be responsible for the control and management of spacecraft operations, including orbit maintenance and spacecraft health. This responsibility will begin with the acquisition of the spacecraft after launch, followed by deployment of the solar array and the SAR antenna and subsequent on-orbit check-out and commissioning sequences. Daily, the MCF will generate command sequences and monitor their execution by analyzing the telemetry received from the spacecraft. There will be two Telemetry, Tracking and Command (TTC) stations in Canada; one in St. Hubert near the MCF and the other in Saskatchewan. In addition, NASA's Deep Space Network will be used for launch and early orbits and subsequently when required. These TTC stations will be operating at S-band. The MCF and TTC stations will operate 24 hours a day, 7 days a week while the MMO is planned to be staffed during normal working hours five days a week.

Spacecraft: The spacecraft (Figure 2) will weigh approximately 3200 kg and extend 15m in length and it will consist of a bus module with a solar array and antennas for telemetry/command and SAR data link, and a payload module containing the two tape recorders and a SAR instrument with its transmit/receive antenna. The 25m² solar array, consisting of the two nominally fixed panels during the normal operation, will generate 3.4 kw of power at the beginning of life. This power will be sufficient for the required 28 minutes of SAR operation during the non-eclipse part of the orbit. The electrical energy storage and bus voltage are to be provided by three 48 ampere-hour NiCd batteries. The command and telemetry link at S-band will permit simultaneous reception of commands and transmission of the telemetry. On-board storage of commands by the spacecraft computer will allow 24 hours of autonomous operation. There will be two SAR data links at X-band, which can be operated

simultaneously. One channel will be for the direct down-link at 105 Mbits/s while the other will be at 85 Mbits/s for the tape recorded data. Each of the tape recorders will be capable of storing at least 10 minutes of SAR data at a recording and replaying rate of 85 Mbit/s.

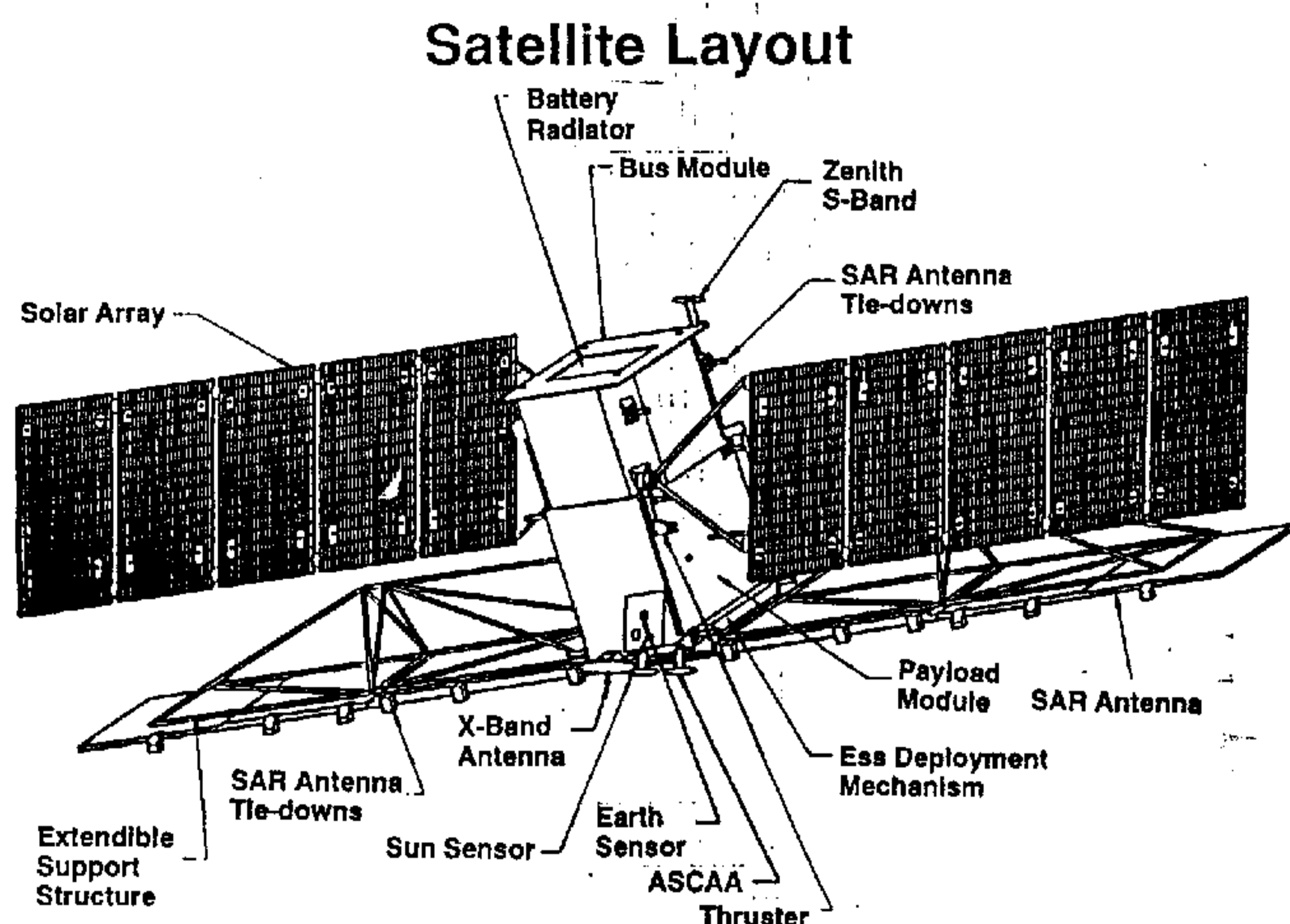


Figure 2.
RADARSAT Spacecraft Configuration

The spacecraft bus will use momentum biased attitude control to provide the required 0.1° pointing accuracy in the 3-axes. With momentum wheels and magnetorquers, it will have horizon scanners and sun sensors. It will start controlling attitude upon separation of the spacecraft from the launch vehicle and maintain correct SAR antenna pointing during routine operation. In the event that the spacecraft attitude is lost or if the attitude control processor fails, it will provide a "Safe Hold Mode" for the spacecraft. The spacecraft bus also includes a mono-propellant hydrazine (N_2H_4) blowdown propulsion module with six thrusters for orbit velocity and inclination changes necessary to meet the orbit maintenance requirements.

SAR Payload: Because the resolution and incidence angle observation needs of the various remote sensing applications differ significantly, the RADARSAT SAR as a central mission requirement, will provide options to users in the selection of swathwidth, spatial resolution, and angle of incidence. Consequently, the designed SAR provides electronically steerable antenna beam in the elevation or range direction to cover the required incidence range (20° to 50°) along with the pulses of different bandwidths for the required range of resolutions. As illustrated in Figure 3, these options will be available through various SAR modes of operation selectable by the ground control. Within the accessibility ground swath of 500 km, it will be possible to select the individual beams or the SCANSAR with the associated swathwidth and resolution. Selected coverage will be possible outside this range.

Ground SAR Data Reception and Processing: The existing Canadian stations at Prince Albert and Gatineau, in use for the reception of data from several satellites (including ERS-1, SPOT and LANDSAT) are being modified to receive real-time and recorded SAR data from RADARSAT. The present ERS-1

SAR data processing facility at the Gatineau receiving station is also being upgraded to meet largely Canadian needs for the processing of RADARSAT data. The Canadian facility will start with a one-tenth real-time speed processor and a flexible design which will allow field upgrades for improving speed and/or throughput capacity as the demand increases during the five year operational phase. It will use a SPECAN algorithm for SCANSAR processing and range doppler for all other processing. This facility to be operated by RSI will produce georeferenced, system geocoded, precision geocoded, and special data products as required by the user community for delivery on a variety of media, such as film, Computer Compatible Tape, and Exabyte tape. The Canadian ground segment development also provides for interface with a data transfer network using the ANIK communications satellite, so that data received at the Prince Albert station can be transferred to the Gatineau station for processing in a time frame which meets the less than four hours turn-around requirements of the Canadian Ice Centre. An image transfer network is being upgraded to move the processed data at the T1 link speed of 1.544 Mbit/s from the Gatineau processing facility to this centre in Ottawa.

NASA will receive SAR data at its station at Fairbanks, Alaska which will have the processing capability as well. In addition RSI has started making arrangements with stations in other countries to receive RADARSAT data directly in return for reception fees, which would include royalty paybacks to the Government of Canada. These stations will likely have their own processing facilities. The licensing agreements for reception and processing will include specification of data formats, procedures for communications with the MCS, data products standards and quality control, data archival requirements and structure of the fee payments. The facilities around the world which are receiving and/or processing European ERS-1 SAR data can be easily upgraded for RADARSAT as being done for the Canadian facilities. This is possible due to the similarities in data rates, data link frequencies and SAR processing technology.

Mode	Width (km)	Resolution $R \times A_z$ (m)	Looks	Incidence Angle (deg)
Standard	100	25×28	4	20 - 49
Wide Swath	(1) 165	$48 \cdot 30 \times 28$	4	20 - 31
	(2) 150	$32 \cdot 25 \times 28$	4	31 - 39
Fine Resolution	45	$11 \cdot 9 \times 9$	1	37 - 48
SCANSAR	(Narrow) 305	50×50	2 - 4	20 - 40
	(Wide) 510	100×100	4 - 8	20 - 49
Extended	(High) 75	$22 \cdot 19 \times 28$	4	50 - 60
	(Low) 170	$63 \cdot 28 \times 28$	4	10 - 23

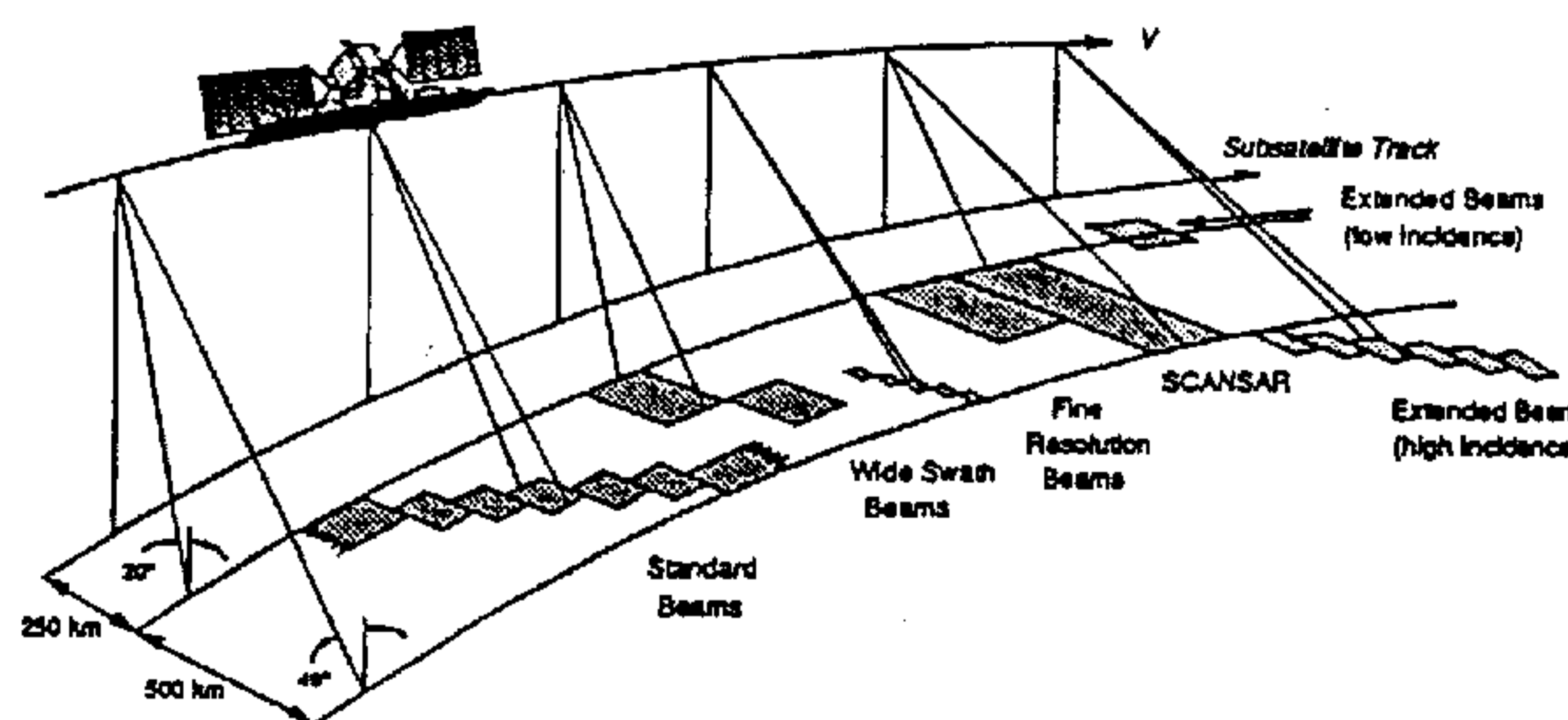


Figure 3.
RADARSAT SAR Modes of Operation

Orbit and Coverage

The RADARSAT spacecraft will operate in a sun-synchronous polar orbit, which crosses the equator in a southerly direction at dawn and a northerly direction at dusk. This dawn-dusk orbit has been selected as it enables the spacecraft to be in sunlight almost continuously, with the exception of some eclipse for a few weeks during June-July. This simplifies the design of the solar array and reduces the demand for battery power. Moreover, this orbit avoids conflict in data reception on the ground with the other Earth observation satellites which typically cross the equator around 10:00 A.M. or 02:00 P.M. A fixed 24 day exact repeat cycle orbit with 343 revolutions per 24 days has been selected for the RADARSAT mission. The spacecraft will circle the earth $14\frac{7}{24}$ times in 24 hours with the orbit altitude of approximately 798 km and inclination of about 98.6° . The $\frac{7}{24}$ is selected to provide a temporally inter-leaved pattern of ground tracks, with a 7 day and a 3 day sub-cycles, which optimizes the revisit opportunities.

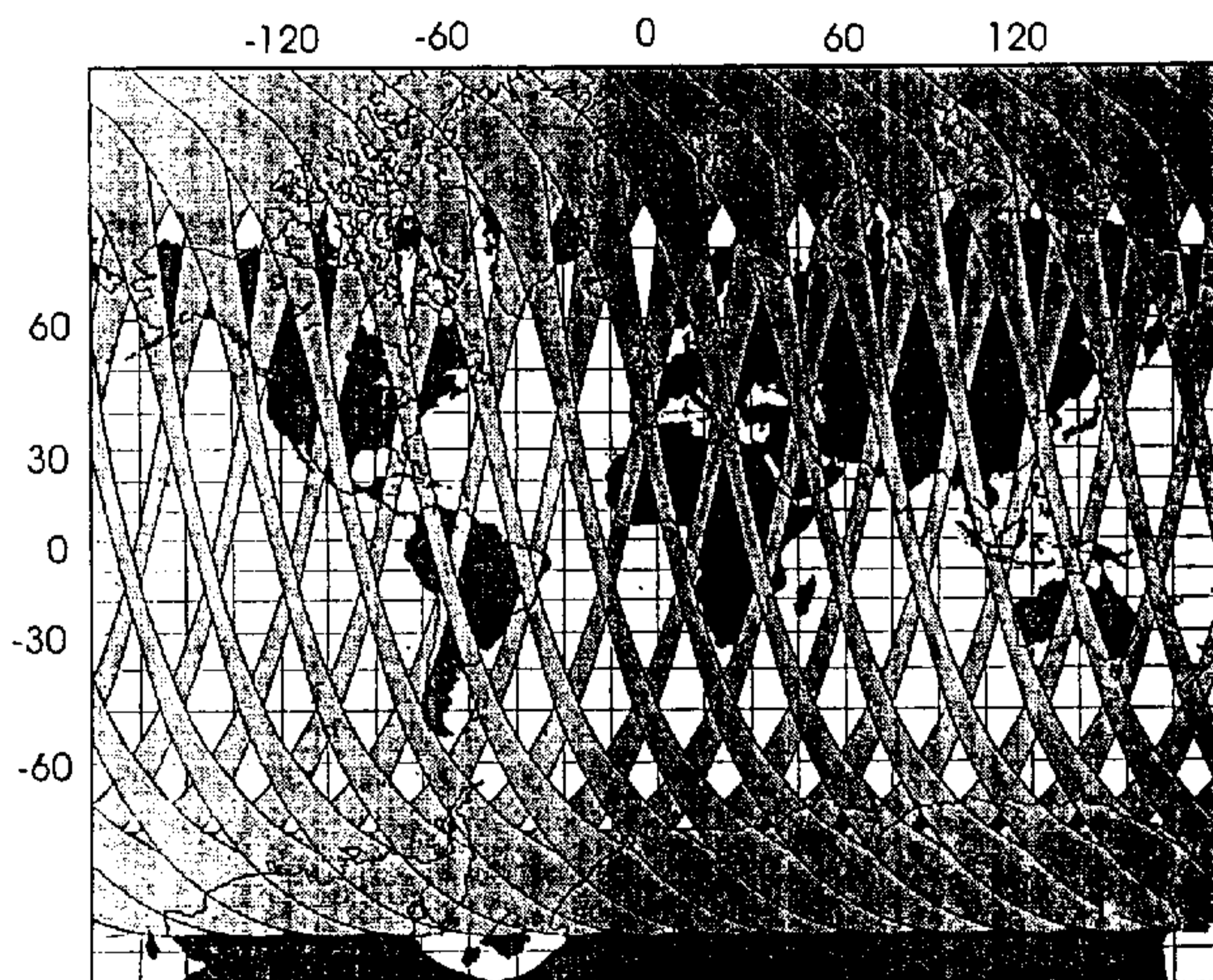


Figure 4.

RADARSAT One Day Ground Coverage (500 km swath)

In normal orientation, the RADARSAT SAR will look right of the satellite track. This north looking orientation has been selected to provide essentially complete coverage of the Arctic. The one-day global accessibility available with the 100 km standard swaths, which is equivalent to the one-day coverage using the 500 km SCANSAR mode is shown in Figure 4. Accordingly, this provides for a daily coverage of the Arctic, an almost complete coverage of Canada and the USA each 3 days period, and a global coverage over approximately 5 days. However, there remains a gap over the Antarctic. To fill this gap as much as possible, the spacecraft will be capable of undertaking manoeuvres through 180° about the yaw axis so that the SAR can look to the left (south) for a period of approximately two weeks, twice during the five year mission. This capability is being provided to meet the NASA requirement of mapping the Antarctic, once during a winter season and once during a summer season, corresponding normally to the maximum and minimum formation of ice, respectively. This Antarctic mode operation requirement has been a design driver for the thermal sub-system (e.g. in heater

and radiator sizings and component temperature limits) of the spacecraft, as the sunlit/space pointing surfaces are reversed and result in large temperature swings. In this Antarctic orientation the SAR will be capable of collecting data for at least 12 minutes per orbit in comparison to the 28 minutes per orbit of SAR on-time during the normal orientation, within the 100 min. orbit.

SAR Image Quality

In view of increasing number of remote sensing applications requiring quantitative information from sensor observations, RADARSAT program is paying particular attention to the knowledge and maintenance of the SAR image quality, such as radiometric and geometric accuracies, during the mission. Image quality parameters (ambiguity ratios, signal dependant noise, radiometric accuracy, geometric location accuracy and distortions) have been specified for the end-to-end SAR system including the ground processor. These specifications will be achieved by employing the internal calibration of the SAR sensor in conjunction with the natural targets and mostly active calibration devices on the ground. SAR measurements over the ground calibration sites, especially those in Canada, together with on-board calibration data will be used to revise antenna beam shape tables that are uplinked to the spacecraft and to calculate the geometric and radiometric corrections for use in data processors. Also, the spacecraft orbit location and repeat ground track accuracies will be maintained to those required for the absolute image location accuracy (at least 1500m and preferably less than 750m) using only the ephemeris or orbit predict data contained in the X-band downlink.

Applications Development and Research Opportunity (ADRO)

CSA, NASA and RSI are working together in planning and implementing the RADARSAT ADRO which is to be announced soon. CSA has recently distributed a pre-announcement letter to over 14,000 persons around the world to solicit potential interest in such a program. The ADRO will be a formal competitive process which will bear many similarities to the familiar "Announcements of Opportunity" issued by NASA for research purposes. The emphasis in ADRO, however, will be equally on, scientific research and development, and demonstration of new products, applications, or services, especially of operational use. Consequently, the ADRO will be open to international scientific community, value-added companies, and end users, for them to submit proposals in accordance with the guidelines to be announced with the request for proposal. The received proposals will be evaluated according to established criteria and the selected investigators will be provided with agreed upon quantities of RADARSAT data. In return for this "free" data, the investigator will be required to at least submit reports of their findings and publish and present the results at a symposium. CSA is presently setting up a coordinating office and the ADRO should be formally announced this summer and the successful projects should be selected by the end of 1994.

System Implementation Status

The design and manufacture of flight hardware and ground control equipment are well advanced at the prime contractor

Spar Aerospace in Quebec and its major subcontractors CAL Corporation, COMDEV, MacDonald Dettwiler and Associates, SED Ltd, and others across Canada. The spacecraft bus (without the solar array) built by Ball Aerospace, has been delivered for assembly with the payload. The high power microwave amplifier, similar in design to the one used in ERS-1, has been delivered by Dornier to Spar. The two on-board tape recorders which are similar in design to those employed on the LANDSAT and SPOT programs have been built and delivered by Odetics. Environmental tests on the solar array and the SAR antenna have been completed as well as the spacecraft to the NASA Deep Space Network interface tests. Spar has started the integration of the payload and the bus at the David Florida Laboratory of CSA in Ottawa, where the final integration and testing of the complete spacecraft will take place during 1994. Moreover, the ground segment elements are at the various stages of development. The 10m diameter antennas at the two Canadian TTC stations have been installed. The MCS, calibration workstations and transponders (similar in design to those used for ERS-1) and Canadian data reception and processing facilities have all undergone critical design reviews. The spacecraft simulator (to be used for operator training) and order-desks are in the early stages of development. RSI has been giving seminars on characteristics and applications of RADARSAT and has started to develop agreements with interested reception facilities and users (outside the Canadian and USA governments).

The classroom training of spacecraft operators has been started as well as the development of operational plans, including compilation of data acquisition needs. It is planned to develop pre-launch candidate data acquisition plans so that the mission can start producing as soon as the system is declared operational following the nominal 3 months of commissioning period after the spacecraft launch. These advance plans will include those data requests which can be determined now, such as the data requirements under ADRO, ice monitoring data needs for the Arctic and the Antarctic, the global data set for geological mapping, representative data samples around the world for various application, etc. These plans will of course be updated during the course of the mission and be merged with the modified or new requests from the user community. This approach will allow an early and orderly resolution of conflicts and a balanced and timely allocation of system resources which meet the diverse needs of programs partners, applications and user groups.

BEYOND RADARSAT I

With the design life of five years, the RADARSAT I should continue supplying SAR data to the world user community at least till the year 2000. The development of applications and associated utilization technology and the development of market for RADARSAT data are already underway through efforts of CSA, RSI, CCRS, NASA, NOAA and others. To strengthen this development and commitment of users to invest in SAR data utilization, the users need to be assured of the continuity of RADARSAT SAR data. Accordingly, it has been accepted that continuation of the RADARSAT program beyond RADARSAT I is vital to realize the applications and economic benefits expected from the program. In recognition of this need, CSA has developed a plan for the follow-on to RADARSAT I under the next Long Term Space Plan (LTSP) for Canada. The Canadian Government announced approval of

the LTSP with associated funding on June 3, 1994. Under the LTSP, the RADARSAT II project will be started during the 1994/95 fiscal year, for the spacecraft to be ready for launch in the 1999/2000 time frame.

RADARSAT II is presently conceived to be essentially a copy of RADARSAT I. However, the LTSP requires a greater investment from the private sector in RADARSAT II and the development of a partnership between government and industry. The nature of this relationship, which remains yet to be established, may have some influence on the characteristics of RADARSAT II. Nevertheless, the mission capability of RADARSAT I, in terms of data products and choices of incidence angles, resolutions, and swath widths will continue to be available with RADARSAT II. NASA will contribute the launch and possibly a Global Positioning Satellite (GPS) receiver for the spacecraft in return for which it will receive a share of data acquisition privileges under the terms and conditions similar to the NASA - CSA Memorandum of Understanding for RADARSAT I. The inclusion of GPS would enhance spacecraft position and image location accuracies and make data processing easier, thereby increasing the value of the SAR data for scientific applications.

In parallel with RADARSAT II, the LTSP has also approved funds for work on enabling technologies for follow-on to RADARSAT II. This would entail advanced system and technology development for the SAR and key ground segment elements such as spacecraft control, mission planning and data processing. An User Development Program for RADARSAT has also been approved under the LTSP. This program would support development of RADARSAT SAR applications and value-added products and services so as to enhance utilization capability of users.

CONCLUDING REMARKS

With RADARSAT I, Canada will be taking a major step in remote sensing, by becoming for the first time a supplier of Earth observation data. As a result the world user community will have access to a versatile and advanced SAR system with multi-incidence angles and multi-resolutions observation capability which is operationally responsive to needs of each user in terms of turn-around time, frequency of observation, and data quality. RADARSAT I mission will, for the first time, allow high resolution mapping of the Antarctica and it will also pioneer: the use of the dawn-dusk orbit, the SCANSAR operation for wide swath imaging, and the much longer design life of five years than the traditional 2 to 3 years for similar missions. The recent approval of RADARSAT II demonstrates Canada's commitment to the continuity of SAR data in servicing the international remote sensing market.

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